Associations between obesity and cognition in the pre-school years

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What is Known on This Subject

Recent systematic review evidence of sixty-seven studies indicated that childhood obesity is negatively associated with aspects of neurocognitive functioning including executive function, attention, and visuospatial performance.

Recent evidence suggests that obesity is associated with poorer cognitive outcomes and impaired educational attainment in adolescent girls.

The issue of *when* lower cognition and educational attainment related to obesity develop during childhood and adolescence is unclear.

What This Study Adds

Reduced obesity-associated performance in some cognitive abilities emerges in the pre-school years.

Lower performance in some cognitive abilities associated with obesity was not substantial in the pre-school years and might gain practical significance later in childhood or adolescence.

Abstract

Objective To test the hypothesis that obesity is associated with impaired cognitive outcomes in the pre-school years.

Methods Associations were examined between weight status at age 3-5 years and cognitive performance at age 5 years. Cognitive outcome measures were tests of Pattern Construction (visuo-spatial skills), Naming Vocabulary (expressive language skills), and Picture Similarity (reasoning skills). The sample was the UK Millennium Cohort Study (MCS; n 12,349 participants).

Results Boys with obesity at 3 years had significantly lower performance in Pattern Construction at age 5 years compared to those of a healthy weight, even after controlling for confounders (β= -0.029, p=0.03). Controlling for confounders, boys who developed obesity between the age of 3 and 5 years had lower scores in Pattern Construction (β=-0.03, p=0.03). 'Growing out' of obesity had a beneficial impact on Picture Similarity performance in girls (β=0.03, p=0.04).

Conclusions Obesity in the pre-school years was associated with poorer outcomes for some cognitive measures in this study. Stronger relationships between obesity and cognition or educational attainment may emerge later in childhood.

Introduction

Childhood obesity has a variety of adverse consequences, in the short and long-term (1, 2). A systematic review by Caird et al tested the hypothesis that child or adolescent obesity impairs educational attainment (3), but found that the evidence was unclear because most previous studies had serious limitations, notably cross-sectional design, lack of control for socio-economic status (SES), an important confounder, and small sample size. Liang et al (4) recently reviewed the neurocognitive impacts of child and adolescent obesity, and concluded that while obesity related deficits in cognition were likely, there was a lack of empirical evidence, and a need for longitudinal studies to address the issue.

Historically, psychometric intelligence quotient (IQ) tests designed for young children emphasize expressive language ability, visuospatial skills and non-verbal reasoning. Early indicators of IQ are implicated at older ages and important for attainment (5, 6, 7) . Evidence in older children suggests a negative association between obesity and language ability, visuospatial skill and non-verbal reasoning (4). Whether this adverse relationship emerges in early childhood needs to be explored.

In a recent English cohort study, obesity at age 11 years was associated with a marked deficit in subsequent educational attainment (up to age 16 years) in girls, but not boys(8). The impact of obesity on educational attainment might be useful to support arguments for school-based obesity prevention initiatives since educational attainment is so highly valued by families and school systems (8). Furthermore, knowledge of *when* obesity-related deficits in attainment emerge, and how large the deficits are at various ages, may also be useful in translating evidence on this topic into policy

aimed at preventing obesity. In the UK, as in the USA and many other parts of Europe, formal education now begins in the pre-school period, at age 3-5 years, and there is increasing emphasis on the importance of the pre-school period for subsequent academic outcomes (9). There is therefore a need to test whether, and to what extent, pediatric obesity is associated with cognitive function and educational attainment in the crucial pre-school years.

In addition to emerging epidemiological evidence that obesity may impair cognition and/or educational attainment (4, 8), a number of plausible biological mechanisms linking obesity to impaired cognitive function have now been identified both in humans and in animal models (10, 11, 12, 13, 14, 15).

The primary aim of the present study was to test the hypothesis that obesity in early childhood is associated independently with impaired cognitive outcomes in a large, longitudinal, UK birth cohort study, the Millennium Cohort Study (MCS;(16)) .

Methods

Study cohort

The sample comprised participants from the MCS (17), a nationally representative longitudinal study of 18,819 infants. A random two-stage sample of all infants born between 1 September 2000 and 31 August 2001 (for England and Wales), and between 24 November 2000 and 11 January 2002 (for Scotland and Northern Ireland), alive in the UK at age nine months was drawn from child benefit (a universal benefit paid to mothers) registers. The sample was clustered geographically at electoral ward level and was disproportionately stratified to over-represent areas with high

proportions of ethnic minorities in England, areas of high child poverty, and those living in the three smaller countries of the UK. The interview response rate was initially 82%; at first follow-up 80% (2003/2004) and at second follow-up 79% (2005/2006). Study enrolment is described in more detail elsewhere (16). Ethical approval for the study was obtained from the UK National Health Service Ethical Authority, and informed written consent was provided by all parents/guardians.

In order to account for maternal education and post-pregnancy body mass index (BMI) participants were included in this study where the main interview respondent was the natural (n=12,336, 99.9%) or adoptive (n=12, 0.1%) mother. Children were also excluded when parents reported children were diagnosed with relevant cognitive impairments, i.e. attention deficit hyperactivity disorder (ADHD; n=116, 0.8%) or autism/Asperger's syndrome (n=107, 0.8%).

Characteristics of study participants

Objective measurements of height and weight were made in 12,349 participants at age 3 years: 76.5% with healthy weight (4,783 male; 4,665 female); 18.0% with overweight (1,080 male; 1,183 female); 5.5% with obesity (332 male; 351 female). Measurements of weight status at age 3 and 5 years old were available for 12,292 boys and girls. Between age 3 and 5 years 91.0% (5,634 male, 5,549 female) of the children were never with obesity, 3.1% (202 male, 178 female) 'grew out' of obesity, 3.5% (206 male, 220 female) developed obesity, and 2.5% (130 male, 173 female) were persistently with obesity. Following the application of exclusion criteria, data for 12,262 (Picture Similarity), 12,281 (Naming Vocabulary), and 12,243 (Pattern Construction) participants remained for analyses. Table 1 provides characteristics of

study participants and Table 2 shows mean T-scores for each cognitive test by weight status at 3 years old.

When comparisons of characteristics were made between those who participated at age 3 years and those who did not, small differences were found in income, maternal education, maternal age at child birth, and birth weight.

Predictor variables, outcomes and confounders

Weight status predictor variables

Children's weight (measured without shoes or outdoor clothes) and height was measured according to MCS standard protocols. Weight status was defined on the basis of the body mass index (BMI) for age relative to age and gender-specific UK 1990 population reference data (18). Healthy weight was defined as BMI percentile $\leq 84.9^{th}$, overweight as BMI percentile 85.0^{th}-94.9^{th}, and obesity as BMI percentile $\geq 95.0^{th}$.

Cognitive outcome variables

Three academically relevant cognitive outcome measures from the MCS cohort aged 5 years were obtained using the British Ability Scales (BAS) II and so these were used for the present analyses. For detailed information on how and by whom children were assessed the reader is referred to the MCS User Guide (19). The outcome measures were Naming Vocabulary, Picture Similarity and Pattern Construction. Normative scores were used for the analysis (T-scores with a mean of 50 and standard deviation of 10) (20). BAS II showed construct validity as measure of cognitive ability and high test-retest reliability for the three tests administered to children aged 5

years (21): r=0.80 (Naming Vocabulary), r=0.63 (Picture Similarity), r=0.73 (Pattern Construction). The Picture Similarity test measured non-verbal reasoning ability: the child was shown a row of four pictures, given a corresponding card and asked to place the card under the picture which shares an element or concepts with the image on the card (22). Naming Vocabulary assessed children's expressive language ability where they recalled words from long-term memory: test items consisted of a booklet of coloured pictures of objects which the child is shown one at a time and asked to name it; successful performance depends on the child's previous development of a vocabulary of nouns (22). Pattern Construction is a non-verbal test of visuo-spatial skills: the child was asked to construct a design by putting together flat squares or solid cubes with black and yellow patterns on each side; the score is based on accuracy and speed (22).

Statistical analyses

The associations between weight status (children with healthy weight, overweight or obesity) and cognitive abilities were assessed using univariate and multivariate linear regression analyses with weight status as predictor variable with healthy weight as the reference group. As males and females have been found to differ in relation to cognitive ability and educational attainment (23), and research suggests that the relationship between obesity and educational attainment may be sex-specific, at least in adolescence (5), the interaction between sex and weight status was tested formally. There was evidence for interaction effects, therefore analyses were conducted separately for males and females. No interaction effect was detected between ethnicity and weight status.

Potential confounders were included in the analyses due to their possible relationship with the exposure and outcome measures: age; birth weight; maternal smoking during pregnancy (yes/no); maternal-reported child's general health (excellent, very good, good, fair, poor); ethnicity; socio-economic status based on maternal education (no education to education at University degree level), annual household income and number of children in household; language spoken at home (English only to other language only); vocabulary ability at age 3 years measured using the BAS II Naming Vocabulary test; how often parents read to child (daily, 1-2 times/week, several times/week, less often, not at all); child's behaviour reported by the mother using the Strengths and Difficulties Questionnaire (24); and whether the child attended primary school (elementary school). With the necessary exceptions of birth weight, maternal smoking during pregnancy, and vocabulary ability at age 3 years, analyses included confounding variables measured at the follow-up time point of age 5 years. Given that expressive language ability performance measured by the Naming Vocabulary test depends on child's previous development of a vocabulary of nouns we added vocabulary ability at age 3 years as confounder to account for baseline cognitive ability when assessing the association between weight status and cognition at the age of 5 years. Each variable was considered univariately as a predictor of cognition. Those which were found to be significant univariately were then considered in a multivariate analysis.

Five models were used to explore the impact of confounding variables: Model 1 was unadjusted for any confounding variables, Model 2 adjusted for demographic and socio-economic variables (age, ethnicity, maternal education, number of children in

household and family income), Model 3 extended Model 2 by including child's birth weight and maternal smoking during pregnancy. Model 4 extended Model 3 by adding child's general health and Strengths and Difficulties Questionnaire scores. Model 5 included child developmental variables such as how often parents read to the child, whether the child attended primary school and language spoken at home. To the fully adjusted model, vocabulary abilities at age 3 years were added. Confounders not significant in the models were removed.

To investigate whether *change* in weight status between 3 years old and 5 years old had an impact on cognitive performance at age 5 years, weight change status (never with obesity; 'grew out' of obesity; developed obesity from healthy weight or overweight; persistently with obesity) was entered as the predictor variable with never with obesity as the reference group in regression analyses.

SPSS version 21 was employed for all analyses with list wise deletion for regression models. All models were weighted for sampling design and non-response. Combined sample design and non-response weights were available at the MCS dataset. Standard sequential weighting procedures were used to estimate non-response weights after multiple imputation of missing data was performed (19). Significance was considered at the 5% level.

Results

Associations of weight status at age 3 years with cognitive outcomes aged 5 years

Unstandardized and standardized coefficients for the unadjusted and fully adjusted models can be found in Table 3 for boys and Table 4 for girls (results for each step of adjustment available from the corresponding author).

In boys, based on the unadjusted model, there was evidence of a significantly negative association between obesity at age 3 years and Pattern Construction ability at age 5 years: boys with obesity had significantly lower performance in Pattern Construction (visuo-spatial skill) compared to those with a healthy weight ($\beta = -0.033$, $p = 0.01$). Adjustment for the full range of confounding variables showed that obesity at age 3 years continued to predict decreased Pattern Construction performance with only small attenuation of the coefficient ($\beta = -0.030$, $p = 0.03$, adjusted $R^2 = 9.7\%$) and widening of the 95% confidence interval. Associations between obesity and performance in Picture Similarity (reasoning) and Naming Vocabulary were non-significant in the unadjusted and fully adjusted model.

For 3 year old girls with obesity, the beta coefficients revealed lower performance scores in Naming Vocabulary ($\beta = -0.03$, $p = 0.02$) and Pattern Construction ($\beta = -0.03$, $p = 0.01$) at the age of 5 years compared to girls with healthy weight. Findings for Pattern Construction remained significant after adjustment for a wide range of confounders; however when cognitive ability at age 3 years was entered into the model the association became non-significant at the 5% level. There was no group difference for Naming Vocabulary performance after adjustment for SES, ethnicity and age (model 2). There was also no significant association between obesity and performance in Picture Similarity.

Associations of change in weight status between 3 and 5 years old and cognitive outcomes aged 5 years

Results of unadjusted and fully adjusted models for the association between change in weight status between age 3 and 5 years and cognitive ability in boys and girls are shown in Table 5.

Boys who developed obesity between 3 and 5 years had lower Naming Vocabulary scores (β = -0.03, p = 0.04) and Pattern Construction scores (β = -0.03, p = 0.02) at age 5 years compared to boys who were never with obesity. Similarly, boys - with persistent obesity between age 3 and 5 obtained lower Pattern Construction scores (β = -0.03, p = 0.03) compared to boys who were never with obesity. After adjustment for a full range of confounders the group difference remained evident for boys who developed obesity compared to boys who were never with obesity (β = -0.03, p = 0.03, adjusted R^2 = 9.7%). The negative association between persistent obesity and Pattern Construction scores and developing obesity and Naming Vocabulary scores became non-significant after adjustment for socio-economic confounders. There was no evidence of a significant group difference for boy's Picture Similarity performance.

For girls, the unadjusted model suggested a non-significant association between 'growing out' of obesity and Picture Similarity performance (β = 0.02, p = 0.06). However, this association became statistically significant after adjustment for confounders indicating that 'growing out' of obesity predicted better performance in Picture Similarity compared to girls who were never with obesity (β = 0.03, p = 0.03, adjusted R^2 = 6.6%). The unadjusted model indicated for both performance in Naming Vocabulary (NV) and Pattern Construction (PC) that girls who developed

obesity (NV: β = -0.03, p = 0.04; PC: β = -0.03, p = 0.03) or remained with obesity (NV: β = -0.03, p = 0.03; PC: β = -0.03 , p = 0.04) between age 3 and 5 years obtained lower scores than girls who were never with obesity. These associations became non-significant after adjustment for SES, age and ethnicity (model 2).

Discussion

Main findings and study implications

The present study found that obesity at age 3 years was associated with some adverse cognitive outcomes at age 5 years. The adverse association between obesity at age 3 and visuospatial skills (Pattern Construction test) at age 5 in boys with obesity was robust to confounding variables, but only 9.7% of the variation in the pattern construction test was explained by obesity at age 3 years: the biological/educational significance of an association of this magnitude is unclear. In girls, there were no significant associations between weight status and all three cognitive outcomes when fully adjusted for all confounders. Better performance in visuo-spatial tasks in boys than girls has been reported previously, suggesting sex-specific learning strategies (21). 'Growing out' of obesity was associated with better reasoning skills (Picture Similarity test) in girls, but the variability in reasoning skills explained by 'growing out' of obesity in the present study was only 6.6%. Gender differences in associations between obesity and cognition or academic attainment have been reported previously (8, 25, 26). The evidence of differences between the sexes in the present study was not entirely unexpected, though these gender differences are not fully understood at present.

The cognitive outcomes used in the present study are important tests of ability and are related to subsequent educational attainment (20, 22).. Given the apparently large influence of obesity on educational attainment in adolescence, at least in girls (8) it is possible that stronger associations between obesity and assessed cognitive abilities and impaired educational attainment may emerge later in childhood or in adolescence (8). It is also possible that weight status is negatively associated with other important measures of cognitive ability which were not made in the UK MCS, such as attention, impulsivity, and inhibition control at pre-school age (27).

Context and comparisons with other studies

The recent systematic review by Liang et al (4) noted the limited evidence on the cognitive effects of obesity, and the dearth of evidence on this topic from early childhood. Veldwijk et al (28) found no associations between childhood obesity at age 4 years and cognitive ability at age 7 years in a Dutch cohort, but different cognitive constructs were tested (mental processing), the sample size was small (n=236), and power may have been limited. Heinonen et al (29), in a cohort of 1,056 Finnish children, found some evidence that a higher weight gain trajectory up to age 4 years might be associated with lower ability in some cognitive domains at age 5 years. The absence of associations between obesity and some cognitive outcomes in the present study may reflect the specificity of obesity effects on brain development, structure, or function. For example, effects of obesity on visuo-spatial skills are better established than other cognitive effects (27). In addition, it is possible that associations might not be observed at certain ages/stages of development, or because the cognitive tests used in the present study did not adequately map onto the cognitive processes affected by obesity.

Associations between changes in weight status in early childhood and educational attainment appear to have been assessed by only two previous cohort studies (25, 26). Datar and Sturm's study (n~7000) suggested that girls who developed obesity between kindergarten and elementary school grade 3 scored significantly lower in Mathematics and Reading compared to those who were never with obesity (30). This association was non-significant for boys though. Carter et al (31) did not find an association between developing obesity and lower Mathematics scores. However, Carter et al also included children who 'grew out' of obesity between the ages 2-5 years and 8-11 years (n =2,582). Findings indicated that children who 'grew out' of obesity obtained higher Mathematics scores compared to those who were never with obesity (31).

Study strengths and limitations

The present study had a number of important strengths namely: novelty; large sample size; longitudinal design; ability to adjust for a wide range of confounders; objective measures of exposure and outcome variables; independent measures of cognitive outcomes; ability to consider changes in weight status over time.

This study also had a number of limitations. We had measures of some but not all cognitive outcomes as well as confounding or mediating variables. For example, objectively measured physical activity levels are important to account for when assessing the impact of obesity on cognitive ability given that childhood obesity is associated with low level of physical activity (32) and the probable beneficial impact of physical activity on cognitive abilities and educational attainment (33, 34). The loss

of data when adjusting for confounders could be considered a limitation; however results were weighted for participants who did not respond at follow-up. Nevertheless, reduction of sample size in the comparison groups potentially reduced the statistical power to detect an impact of obesity on cognitive outcomes. Age and gender specific BMI cut-offs were used as measures of overweight and obesity; however BMI is an acceptable but imperfect measure of obesity. The use of change in age and gender-specific BMI z-scores between 3 and 5 years as continuous predictor variable was considered given its advantages over categorical weight status. However, the MCS data set included BMI and categorical weight data (i.e healthy weight, overweight, obesity) only. The present study was observational, and intervention studies would provide stronger evidence of the impact of obesity on cognitive outcomes.

Adverse effects of obesity on educational attainment-related cognitive abilities are plausible given the fact that plausible mechanisms have been identified (10, 12, 13, 14, 15), but also that poorer performance in some cognitive tests are associated with susceptibility to obesity (4). For example, when compared to healthy weight children, children with obesity show higher impulsivity and lower self-regulation, attention and mental flexibility (35, 36, 37). Hence the association between childhood obesity and cognitive abilities might be reciprocal. Intervention studies might provide useful evidence on effects of obesity on cognitive and educational outcomes, but most interventions which aim to improve weight status in children and adolescents with obesity often report small-modest effects (38, 39), and in any event, a recent Cochrane review found a dearth of obesity intervention studies with cognitive or educational outcome measures (40).

Conclusions

This study suggests that obesity in early childhood may be weakly associated with some poorer cognitive outcomes in the pre-school to early school years. Since stronger relationships between obesity and educational attainment have been described in English adolescents (8), it is possible that any adverse impact of obesity on cognition or educational attainment may emerge later in childhood, or in adolescence.

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Table 1 Demographic, socio-economic, health and developmental characteristics for the total sample and by weight status at 3 years old

Characteristics	**Total Sample**		**Healthy Weight**		**Overweight**		**Obesity**	
	n	**Means (SD)**	**n**	**Means (SD)**	**n**	**Means (SD)**	**n**	**Means (SD)**
Age (years) at baseline	12349	3.1 (0.2)	9309	3.1 (0.8)	2187	3.1 (0.8)	671	3.2 (0.9)
Age (years) at follow up	12348	4.8 (0.4)	9447	4.8 (0.4)	2218	4.8 (0.4)	683	4.8 (0.4)
OECD equalised annual household income (British Pounds)	12286	359.3 (220.3)	9401	362.2 (223.1)	2205	357.4 (210.0)	680	325.6 (210.2)
Maternal BMI (kg/m^2)	10425	25.1 (5.0)	8007	24.9 (4.8)	1860	26.0 (5.1)	558	27.5 (6.3)
Birth weight (kg)	11864	3.3 (0.6)	9077	3.3 (0.6)	2132	3.5 (0.4)	655	3.5 (0.6)
Strengths and Difficulties score	11974	7.1 (4.7)	9151	7.0 (4.7)	2170	7.0 (4.7)	653	7.7 (5.0)
Naming Vocabulary T-score at 3 years	11851	50.0 (11.2)	9084	49.9 (11.2)	2124	50.7 (11.1)	643	49.2 (11.7)
	n	**Proportion**	**n**	**Proportion**	**n**	**Proportion**	**n**	**Proportion**
Gender								
Boys	6195	50.2%	4783	50.6%	1080	48.7%	332	48.6%
Girls	6154	49.8%	4665	49.4%	1138	51.3%	351	51.4%
Child's ethnicity	12345							
White	10555	85.5%	8019	94.9%	1974	89.1%	562	82.4%
Mixed	336	2.7%	255	2.2%	60	2.7%	21	3.1%
Indian	297	2.4%	264	2.8%	26	1.2%	7	1.0%
Pakistani/Bangladeshi	648	5.2%	521	5.5%	79	3.6%	48	7.0%
Black/Black British	359	2.9%	264	2.8%	59	2.7%	36	5.3%
Other	150	1.2%	124	1.3%	18	0.8%	8	1.2%
Language spoken in household	12349							
English only	10770	87.2%	8196	86.7%	1997	90.0%	577	84.5%
Mostly English	607	4.9%	492	5.2%	83	3.7%	32	4.7%

Half English, half other	489	4.0%	381	4.0%	70	3.2%	38	5.6%
Mostly other	422	3.4%	329	3.5%	60	2.7%	33	4.8%
Other language only	61	0.5%	50	0.5%	8	0.4%	3	0.4%
Number of children in household	12349							
1 child	1930	15.9%	1452	15.4%	357	16.1%	121	17.7%
2 children	5842	47.3%	4470	47.3%	1082	48.8%	290	42.5%
3 children	2973	24.1%	2288	24.2%	513	23.1%	172	25.2%
4 children	1132	9.2%	879	9.3%	192	8.7%	61	8.9%
5 or more children	472	3.8%	359	3.8%	74	3.3%	39	5.7%
Maternal education	11344							
University degree	1622	14.3%	1273	14.7%	281	13.8%	68	11.0%
Diploma/further education	1145	10.1%	870	10.0%	211	10.3%	64	10.3%
A levels/Scottish Higher	859	7.6%	673	7.8%	150	7.3%	36	5.8%
O levels/ CSE	3556	31.3%	2714	31.8%	657	32.2%	185	29.8%
Other	774	6.8%	587	6.8%	137	6.7%	50	8.1%
None	3388	29.9%	2565	29.5%	605	29.6%	218	35.1%
Maternal smoking during pregnancy	11880							
Yes	1767	14.9%	1301	14.3%	337	15.8%	129	19.7%
No	10113	85.1%	7786	85.7%	1800	84.2%	527	80.3%
Maternal general health	13345							
Excellent	2771	20.8%	1972	20.9%	472	21.3%	126	18.5%
Very good	4915	36.8%	3475	36.8%	827	37.3%	253	36.1%
Good	3855	28.9%	2736	29.0%	619	27.9%	197	28.9%
Fair	1444	10.8%	997	10.6%	247	11.1%	86	12.6%
Poor	360	2.7%	267	2.8%	52	2.3%	20	2.9%
Child’s general health	12349							

Excellent	6477	52.4%	4912	52.0%	1225	55.2%	340	49.8%
Very good	3810	30.9%	2936	31.1%	665	30.0%	209	30.6%
Good	1552	12.6%	1221	12.9%	235	10.6%	96	14.1%
Fair	447	3.6%	334	3.5%	82	3.7%	31	4.5%
Poor	63	0.5%	45	0.5%	11	0.5%	7	1.0%
In primary school	12349							
Yes	12207	98.9%	9328	98.7%	2200	99.2%	679	99.4%
No	142	1.1%	120	1.3%	18	0.8%	4	0.6%
Read to child	12349							
Every day	6388	51.7%	4902	51.9%	1128	50.9%	358	52.4%
Several times a week	3516	28.5%	2682	28.4%	646	29.1%	188	27.5%
Once or twice a week	1764	14.3%	1335	14.1%	339	15.3%	90	13.2%
Once or twice a month	324	2.6%	255	2.7%	51	2.3%	18	2.6%
Less often	181	1.5%	142	1.5%	26	1.2%	13	1.9%
Not at all	176	1.4%	132	1.4%	28	1.3%	16	2.3%
Playing physically active games	12347							
Every day	781	6.3%	576	6.1%	153	6.9%	52	7.6%
Several times a week	2208	17.9%	1697	18.0%	396	17.9%	115	16.8%
Once or twice a week	4378	35.5%	3382	35.8%	781	35.2%	215	31.5%
Once or twice a month	2186	17.7%	1687	17.9%	379	17.1%	120	17.6%
Less often	1709	13.8%	1277	13.5%	323	14.6%	109	16.0%
Not at all	1085	8.8%	827	8.8%	186	8.4%	72	10.5%

Table 2 Participants' cognitive ability T-scores at age 5 years by weight status assessed at 3 years old

Cognitive outcomes	Healthy weight				Overweight				Obesity			
	Boys		Girls		Boys		Girls		Boys		Girls	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Picture Similarity	4736	55.06 (10.11)	4615	56.35 (10.18)	1070	55.66 (10.33)	1120	56.24 (9.91)	328	55.41 (10.25)	346	56.58 (11.08)
Naming Vocabulary	4741	54.05 (11.39)	4626	54.78 (10.61)	1069	55.46 (10.95)	1126	55.01 (10.19)	328	53.90 (11.37)	346	53.55 (11.06)
Pattern Construction	4724	49.94 (10.19)	4611	51.53 (9.31)	1067	50.03 (10.30)	1123	51.61 (9.67)	328	48.66 (10.76)	345	50.48 (9.38)

Table 3. Weight status at age 3 years predicting Picture Similarity, Naming Vocabulary, and Pattern Construction abilities in 5 year old **boys** (reference group = healthy weight)

	Unadjusted model					Fully adjusted model [a,b,c]				
	n	B (SE)	95% CI	β	*p*	n	B (SE)	95% CI	β	*p*
Picture Similarity	6134					5223				
Overweight	1070	0.36 (0.34)	-0.31,1.03	0.014	0.29	929	0.10 (0.35)	-0.59, 0.02	0.004	0.78
Obesity	328	-0.42 (0.60)	-1.60,0.76	-0.009	0.49	273	-0.07 (0.63)	-1.16, 1.45	0.002	0.91
R^2 change	0.000					0.022				
Naming Vocabulary	6138					5230				
Overweight	1069	1.31 (0.37)	0.58, 2.04	0.045	<0.01	931	0.88 (0.32)	0.26, 1.50	0.03	<0.01
Obesity	328	-0.12 (0.66)	-1.41,1.12	-0.002	0.85	273	0.35 (0.57)	-0.76, 1.46	0.01	0.53
R^2 change	0.002					0.167				
Pattern Construction	6119					4014				
Overweight	1067	-0.07(0.35)	-0.75, 0.60	-0.003	0.83	929	-0.12 (0.35)	-0.80, 0.56	-0.005	0.73
Obesity	328	-1.55 (0.61)	-2.75, -0.36	-0.033	0.01	272	-1.49 (0.70)	-2.43, -0.004	-0.026	0.05
R^2 change	0.001					0.025				

a) Picture Similarity: adjusted for age, ethnicity, maternal education, family income, birth weight, child health, SDQ scores, vocabulary skills at age 3, b) Naming Vocabulary: adjusted for age, ethnicity, maternal education, family income, birth weight, maternal smoking, child health, SDQ scores, how often parents read to child, language spoken at home, whether in primary school, vocabulary skills at age 3, c) Pattern Construction: adjusted for age, ethnicity, maternal education, family income, number of children in the household, birth weight, SDQ scores, whether in primary school, vocabulary skills at age 3 years

Table 4. Weight status at age 3 years predicting Picture Similarity, Naming Vocabulary, and Pattern Construction abilities in 5 year old **girls** (reference group = healthy weight)

	Unadjusted model					Fully adjusted model [a,b,c]				
	n	B (SE)	95% CI	β	*p*	n	B (SE)	95% CI	β	*p*
Picture Similarity	6081					5223				
Overweight	1120	0.12 (0.34)	-0.55,0.78	0.005	0.72	957	-0.02 (0.35)	-0.71, 0.67	-.001	0.95
Obesity	346	0.76 (0.56)	-1.03,1.18	0.002	0.89	281	0.48 (0.59)	-0.68, 1.64	.011	0.42
R^2 change	0.000					0.019				
Naming Vocabulary	6098					5329				
Overweight	1126	0.07(0.35)	-0.61,0.76	0.003	0.83	962	0.03 (0.30)	-0.57, 0.62	0.001	0.93
Obesity	346	-1.36 (0.52)	-2.49,-0.22	-0.030	0.02	282	0.20 (0.51)	-0.78, 1.20	0.005	0.70
R^2 change	0.001					0.164				
Pattern Construction	6079					5509				
Overweight	1123	0.23 (0.32)	-0.39,0.85	0.010	0.46	815	0.28 (0.32)	-0.35, 0.92	.012	0.38
Obesity	345	-1.34 (0.52)	-2.37,-0.31	-0.033	0.01	230	-.952 (0.54)	-2.01, 0.11	-.023	0.08
R^2 change	0.001					0.027				

a) Picture Similarity: adjusted for age, ethnicity, maternal education, family income, number of children in the household, birth weight, maternal smoking, child health, SDQ scores, vocabulary skills at age 3; b) Naming Vocabulary: adjusted for age, ethnicity, maternal education, family income, birth weight, maternal smoking, child health, SDQ scores, how often parents read to child, language spoken at home, whether in primary school, vocabulary skills at age 3, c) Pattern construction: adjusted age, ethnicity, maternal education, family income, birth weight, maternal smoking, child health, SDQ scores, vocabulary skills at age

Table 5. Associations of change in weight status between 3 and 5 years old and cognitive outcomes (reference group = never with obesity)

	Unadjusted model						Fully adjusted model*					
	Boys			**Girls**			**Boys**			**Girls**		
	n	β	*p*	n	β	*p*	n	β	*p*	n	β	*p*
Picture Similarity	6144			6082			5264			5223		
'Grew out' of obesity	199	-0.004	0.73	175	0.024	0.06	168	0.003	0.83	142	0.028	0.04
Developed obesity	205	-0.023	0.07	216	-0.023	0.07	166	-0.016	0.25	172	-0.001	0.96
Persistent obesity	129	-0.013	0.32	171	-0.024	0.07	106	-0.006	0.67	140	-0.011	0.41
R^2 change	0.001			0.002			0.023			0.019		
Naming Vocabulary	6147			6101			4472			5240		
'Grew out' of obesity	199	0.001	0.92	175	-0.017	0.19	134	0.002	0.84	142	-0.003	0.79
Developed obesity	203	-0.027	0.04	217	-0.027	0.35	134	-0.001	0.95	173	0.007	0.53
Persistent obesity	129	-0.015	0.25	171	-0.029	0.02	90	0.008	0.57	141	0.004	0.47
R^2 change	0.001			0.002			0.167			0.158		
Pattern Construction	6129			6083			5216			5224		
'Grew out' of obesity	198	-0.021	0.11	174	-0.024	0.07	167	-0.022	0.09	141	-0.025	0.06
Developed obesity	203	-0.031	0.02	215	-0.029	0.03	164	-0.029	0.03	171	-0.001	0.92
Persistent obesity	130	-0.029	0.02	171	-0.027	0.04	105	-0.015	0.27	141	-0.012	0.35
R^2 change	0.002			0.002			0.024			0.027		

a) Picture Similarity: adjusted for age, ethnicity, maternal education, family income, number of children in the household, maternal smoking during pregnancy, child healthy, SDQ scores, vocabulary skills at age 3years; b) Naming Vocabulary: adjusted for age, ethnicity, maternal education, family income, number of children in household, maternal smoking during pregnancy, child health, SDQ scores, whether started school, how often parents read to child, language spoken at home, vocabulary skills at age 3years; c) Pattern Construction: adjusted for age, ethnicity, maternal education, family income, number of children in the household, birth weight, maternal smoking during pregnancy, child health, SDQ scores, vocabulary skills at age 3years